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IMPACT OF FENTHION ON NONTARGET BIRDS DURING QUELEA CONTROL IN KENYA

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The red-billed quelea (*Quelea quelea*), a 20-g weaver bird (Family Ploceidae), is the most serious avian pest of grain crops in Africa. It feeds on crops in >25 African nations (De Grazio and Besser 1974, Anon. 1981), exacerbating already serious food shortages. In many African countries, concentrations of quelea are traditionally sprayed with avicides to reduce cereal grain losses (Ward 1973, 1979). Spraying is an effective and widely practiced control technique. Avicides are sprayed from fixed-wing aircraft, helicopters, and ground-spraying equipment.

Quelea nesting colonies occupy from <1 to >100 ha and contain from a few thousand to several million birds. These colonies attract large numbers of avian predators, particularly migrant raptors. Numbers of these raptors can increase progressively between the time young quelea hatch and when they leave the nest, a period of about 14 days (Thiollay 1975, 1978). Raptors prey on young quelea, especially during a period of 7–10 days after they leave the nest, when they are still flightless. When several colonies occur in an area, young in respective colonies often are in different developmental stages, and raptors may feed on these birds sequentially as they become available. Predator density near colonies may be 70–500 times greater than in the general area during the period when quelea breed (Thiollay 1978). Presumably, spraying quelea when flightless young have left the nest and when parents are still in the colony would have the ~~least~~ greatest adverse impact on raptors. Raptors could become poisoned directly by the spray or indirectly by ingesting poisoned quelea.

Fenthion (phosphorothioic acid, *O,O*-dimethyl *O*-[3-methyl-4-(methylthio)phenyl] ester), an organophosphate insecticide marketed as Queletox® (reference to trade names does not imply U.S. Gov. endorsement), is the chemical used most often to spray quelea, and an estimated 1 billion quelea are killed annually in hundreds of nesting colonies and roosts throughout Africa (Ward 1979). Fenthion inhibits cholinesterase (ChE), which results in an accumulation of acetylcholine at nerve syn-

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apses with consequent disruption of nerve function (O'Brien 1967:55). For quelea, the oral LD_{50} is 1.3 mg/kg (Schafer et al. 1973); this is less than the oral LD_{50} for birds in general. The dermal LD_{50} for quelea has been reported to be 1.8 mg/kg (Schafer et al. 1973) and 2.5 mg/kg (Anon. 1979). Bird mortality from dermal applications generally occurs from 3 to 12 hours after exposure, but can take place over a period of days (Schafer 1984).

Possible effects of organophosphate insecticides on wildlife have generated widespread concern (Grue et al. 1983). Raptors often are attracted to areas treated with organophosphates (Zinkl et al. 1979, DeWeese et al. 1983, Thomsett 1984). Secondary exposure to organophosphates kills raptors (Stone et al. 1984; Henny et al. 1985, 1987) or may debilitate them sufficiently that they are more susceptible to predation (McEwen and Brown 1966).

Despite efforts to minimize environmental impacts of organophosphates for quelea control (Bruggers and Jaeger 1982), concern about potential nontarget and environmental impacts has increased in recent years. After a spray operation in Kenya in 1984, many dead or dying eagles, owls, hawks, and secretary birds (*Sagittarius serpentarius*) were recovered (Thomsett 1984, 1987). This mortality was attributed to raptors eating dead and debilitated birds that dispersed from spray sites (M. M. Jaeger, Food and Agric. Organ. of United Nations [FAO], pers. commun.). Because quelea control using low-volume (1–4 L/ha) aerial and ground application techniques is becoming more widespread, secondary effects need to be assessed.

The goal of our study was to assess the potential impact of fenthion on the environment and nontarget birds when applied by low-volume aerial spray techniques to quelea nesting colonies. Our objectives were to determine (1) exposure and mortality pattern of quelea and nontarget raptors; (2) extent of habitat contamination; and (3) spray-related mortality of nontarget seed-eating and insectivorous birds.

STUDY AREA AND METHODS

In April and May 1985, we monitored the impact of fenthion at 2 quelea nesting colonies, designated as Crocodile Colony (10 ha) and Ranch Colony (40 ha), located on the 100,000-ha Kulalu Ranch southeast of Tsavo East National Park along the Galana River, Kenya (3°05'S, 39°15'E). The colonies were about 10 km apart and situated in a savannah of low (2–3 m) thornbush (mix of *Acacia senegal*, *A. ruficiens*, and *A. mellifera*) along seasonal drainages. This is a traditional quelea nesting area between November and March (Allan n.d.); rains in 1985 extended nesting into May.

We mapped and gridded both colonies into 0.25-ha quadrats, then randomly sampled 5 of 34 and 10 of 46 quadrats in Crocodile Colony and Ranch Colony, respectively, to determine the density of acacia trees and quelea nests. We estimated the number of quelea in the colonies based on 2 adults and 2.8 nestlings/nest (Morel and Bourliere 1955, Morel and Morel 1974).

Spray Operations

Both colonies were sprayed by the Desert Locust Control Organization for Eastern Africa (DLCO-EA), which regularly sprays quelea colonies in Kenya, Tanzania, Sudan, Ethiopia, and Somalia. The De Havilland Beaver spray plane was flown at 160–170 km/hour and was fitted with a twin Micronair AU 4000 spray pod system, with spray blade angles set to give volume mean diameter droplets of 80 μm. Crocodile and Ranch colonies were sprayed on 25 April and 4 May, respectively, during a 10-minute period between sunset and dark. The airplane made several passes over each colony in a direction relatively perpendicular to the wind. Total volume sprayed was 40 and 100 L of Queletox (60% active ingredient [a.i.]) fenthion in the 10- and 40-ha colonies, respectively. These were the first spray operations ever conducted in the area, and applications were made solely for this study. Control operations generally are not conducted in this area of Kenya because these quelea concentrations are not associated with agricultural areas. Both colonies were sprayed after young had left nests, but while many were flightless and being fed by adults.

Environmental Assessments

Stickel (1973) recommended that studies of organophosphates include searches for debilitated and dead birds and analyses of brain tissue or blood to determine cholinesterase inhibition. We searched nesting colonies, used mist-nets to capture birds, and employed radiotelemetry to monitor movement patterns of nontarget birds before and after spraying. We made visual counts of raptors. From 1 to 15 individuals each of 21 species of passerines were collected for ChE analysis before and after spraying.

Spray Deposits.—We used thin-layer chromatography plates and filter papers set at ground level along 3 transects to monitor fenthion deposits in colonies. Each transect consisted of 10 stations, 100 m apart, beginning 200 m upwind and running 700 m downwind of the colony center. At Crocodile Colony, 1 line of plates was picked up at 12 hours, another at 24 hours, and the third at 48 hours after spraying. We analyzed each plate separately for fenthion. At Ranch Colony, all papers were retrieved 14 hours after spraying, and papers from comparable locations on each line were composited for analysis. At both colonies, one of a pair of papers at the center of the colony on each transect line was picked up and extracted within 2 hours of spray applications.

Bird Mortality.—To determine the effect of fenthion on quelea and other birds known to be exposed, we placed 5 or 6 quelea in cages (30 × 30 × 30 cm, constructed of 2.5-cm-mesh poultry netting) either on the ground or near the top of a 4-m tree in the center of each colony, and on the ground at 100, 200, and 300 m downwind of both colonies. Fourteen hours after spraying, we picked up the cages, provided water and food for the birds, and then monitored mortality rates for 4 days. Brains of birds that died were removed for ChE analysis, and fenthion residues were extracted from their plumage. In addition, 1–3 individuals of laughing doves (*Streptopelia senegalensis*), harlequin quail (*Coturnix delegorguei*), domestic chickens (*Gallus gallus*), and black-faced sandgrouse (*Pterocles decoratus*) were put in cages in the center of the colonies and exposed to sprays. We observed all birds for signs of toxicity for 5–7 days.

To determine if fenthion residues on feathers of moribund quelea posed hazards to predators and scavengers, we collected 6–15 sprayed and affected quelea daily for 4 days after fenthion application. We analyzed these birds for fenthion residues and brain ChE levels.

We conducted daily searches for dead and affected nontarget birds 1 day before spray applications and for 5 consecutive days starting the morning after spraying. Two to 5 investigators searched each colony and at least a comparable area of surrounding bush that included large trees in which raptors perched. All debilitated nontarget birds were noted and captured when possible; carcasses were saved for ChE measurements.

Birds affected by quelea control sprays often disappear quickly, apparently from being eaten by predators and scavengers. To determine the disappearance rate of dead birds, we placed 2 bird carcasses at each of 25 locations along a meandering 625-m transect in each colony. One leg on each bird was marked with colored tape to distinguish it from birds dying during spray applications. We checked these transects 1 day before and 3 consecutive days after spraying.

Raptor Movements.—We captured raptors in and around colonies using bal-chatri traps (Berger and Mueller 1959) or monofilament nooses attached to fetid baits, and glued radio transmitters to the dorsal base of their tail feathers. Eagle transmitters weighed 18 g, had a battery life of 3 months, and were equipped with mortality circuits that increased the pulse rate after a 1-hour motionless period. We attempted to locate radio-equipped birds daily either from the ground or air.

Food Contamination.—We sampled several materials within colonies to determine potential levels of fenthion on foods eaten by insectivorous or granivorous birds. In Crocodile Colony we tried to collect a representative sample of dead insects 14 hours after spraying by walking through the sprayed area. In Ranch Colony, dead and dying insects were collected 14 hours after spraying within 0.2-m^2 sampling units placed in 100 scattered locations. We collected grass foliage before spraying and for 3 consecutive days after spraying from approximately the same areas in each colony to monitor fenthion residues available to insects and other herbivores. A thin layer of millet seed also was exposed on a tarp in the center area of Crocodile Colony to determine spray contamination on seeds of the sort that might be eaten by birds.

Cholinesterase Levels and Fenthion Residues

Measurements of ChE activity in brain tissue and plasma can be used to monitor exposure to ChE inhibitors such as fenthion (Grue et al. 1983). We took blood samples from birds equipped with radio transmitters to establish pre- and postspray ChE levels. Brain ChE levels also were determined from insectivorous and granivorous birds collected in and around each colony before and after spraying. Because of close proximity of the 2 sprayed colonies, only birds collected before spraying Crocodile Colony should be labeled with certainty as unexposed. However, we did not adhere to this strict interpretation for some species, particularly more sedentary ones. We also considered some sedentary birds unexposed when they were collected several kilometers from colonies after spraying.

In the field, tissue and blood plasma were frozen in liquid nitrogen. Samples remained frozen for 1–4 weeks until analyzed, using methods described by Hill and Fleming (1982). Brain ChE activity was measured as micromoles (μmol) of substrate (acetylthiocholene iodide) hydrolyzed per minute per gram of brain tissue at 25 C. In plasma, ChE activity was measured in milliunits (mU). A unit was defined as that quantity of enzyme that converts a micromole of substrate per minute per milliliter of serum at 25 C.

We removed fenthion residues from surfaces of quelea, grasses, seeds, insects, and filter papers by placing materials in plastic bottles with known amounts of methanol and shaking for 5 minutes. Extracts were stored at 3 C for ≤2 months before being analyzed for fenthion. Samples were prepared for residue analysis by placing in warm water (about 60 C) and evaporating the methanol to a volume of 0.5 ml using a gentle stream of nitrogen. Particulate matter was separated by centrifugation. Reference fenthion standards were prepared in methanol from compounds obtained from the U.S. Environmental Protection Agency Pesticide and Industrial Chemicals Repository and stored at 3 C. Samples were analyzed by capillary gas chromatography. The limit of detection for fenthion was 0.4 μg/ml of sample.

RESULTS

When sprayed with fenthion, Crocodile Colony had about 5,000 adult and 50,000 young quelea between 24 and 28 days of age that were flying among bushes and feeding within the colony. Few adults returned at night to roost with the young in the colony. Ranch Colony consisted of an estimated 0.5–0.75 million adults, young, and eggs. A 10-ha portion had young about 20–22 days old, and the remaining 30 ha contained 1–2-day-old eggs. Young from this later nesting attempt were just out of the nest and highly susceptible to predation. Ranch Colony also contained 1.0–1.5 million roosting quelea, evidently from other nesting colonies in the vicinity.

Spray Deposits

Immediately after spraying, filter papers placed at 3 stations in Crocodile Colony had deposits equivalent to 213, 24, and 52 g/ha of fenthion. Similar samples in Ranch Colony had residues of 109, 524, and 149 g/ha. Deposits were not uniform, probably reflecting efforts of the pilot to apply fenthion to moving concentrations of birds, the recommended spray procedure for quelea control. Differences in deposits also may have been due to windspeed, which was 14.5 km/hour at Crocodile Colony and 3.6 km/hour at Ranch Colony. Residues at both colonies immediately after spraying suggested that <10% of fenthion sprayed actually reached the ground. Much of the chemical apparently was deposited on trees or drifted out of target areas.

Filter papers collected 12 hours after spraying in Crocodile Colony indicated residues were heaviest in the center of the colony (Fig. 1). Residues declined markedly in samples collected 24 and 48 hours after spraying. Residues at Ranch Colony were higher than in Crocodile Colony (Fig. 2). Because of Ranch Colony's larger size, the pilot probably applied fenthion over a 400-m-wide area as he sprayed the milling quelea.

Bird Mortality

None of the caged birds, other than quelea, that had been placed in the colonies died as a result of fenthion spraying. All but 2 of 47 caged quelea exposed in colonies died; the 2 survivors were 300 m downwind in Crocodile Colony. Birds exposed in Crocodile Colony died sooner than those exposed in Ranch Colony even though higher spray deposits were present in the center of Ranch Colony. In Crocodile Colony, all 5 quelea from both the center area and at 100 and 200 m downwind died within 24 hours. Only 1 of 5 quelea exposed 300 m downwind died after 24 hours; it took 48 hours for all quelea to die.

Young quelea in Crocodile Colony began dying in large numbers about 20 hours after spraying, and affected birds were observed on the ground under nesting trees for 4 days following spraying. In Ranch Colony, many dead quelea were found the morning following treatment, and dying quelea were observed for ≤7 days thereafter. Young were found dead in areas of about 11 and 35 km^2 surrounding Crocodile and Ranch colonies, respectively, for 4–7 days after spraying.

The morning after the spray, fenthion residues from feathers of dead or debilitated quelea averaged 44.0 μg/bird in Crocodile Colony and 83.7 μg/debilitated young bird in Ranch Colony (Table 1). This is consistent with our discovery of many more affected birds the morning after spraying in Ranch Colony than in Crocodile Colony. In both colonies, residues

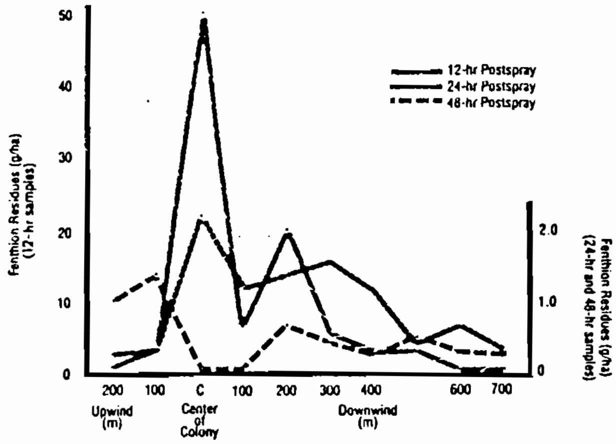

Fig. 1. Fenthion residues extracted from filter papers in Crocodile Colony 12, 24, and 48 hours after aerial spraying for quelea control in Kenya, 1985.

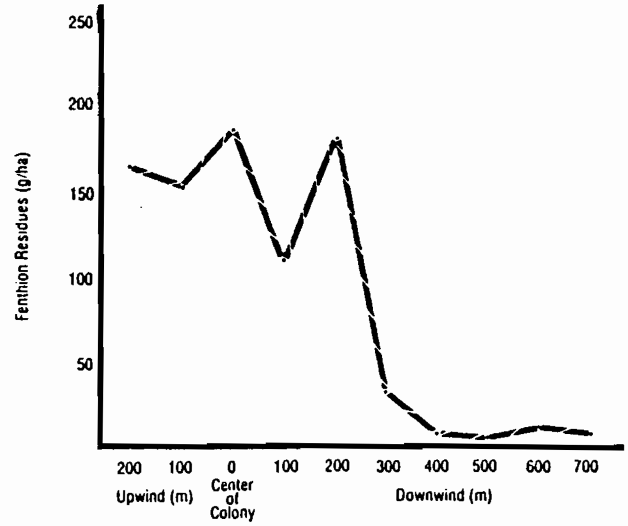

Fig. 2. Fenthion residues extracted from filter papers in Ranch Colony 14 hours after aerial spraying for quelea control in Kenya, 1985.

on young quelea affected by the spray were much lower on subsequent days.

During the first night after spray operations, scavengers removed 24 and 90% of corpses that we had placed along transect lines in Ranch and Crocodile colonies, respectively. Black-backed jackals (*Canis mesomelas*), bat-eared fox (*Otocyon megalotis*), and common genet (*Genetta genetta*) likely were the principal mammalian scavengers. We also saw dwarf mongooses (*Helogale parvula*) and baboons (*Papio cyanocephalus*) feeding on quelea, and heard spotted hyenas (*Crocuta crocuta*) in the area; all of these animals commonly scavenge in quelea colonies.

Raptor Movements

We captured and radioequipped 11 tawny eagles (*Aquila rapax*), 3 bateleur eagles (*Terathopius ecaudatus*), 4 pale chanting goshawks (*Melierax poliopterus*), 2 gabar goshawks (*M. gabar*), 2 pygmy falcons (*Poliohierax semitorquatus*), and 1 pearl-spotted owlet (*Glaucidium perlatum*). These birds were monitored for 2 weeks after Crocodile Colony was sprayed and for 4–8 days after Ranch Colony was sprayed. None were found dead from fenthion poisoning during the period of the study, but several became debilitated.

Twenty of 23 radio-equipped raptors were located after spraying in a colony or in the area around a colony where dying, contaminated quelea were found. One pearl-spotted owlet was found moribund 1 day after spraying and was sacrificed for ChE analysis. One radio-equipped tawny eagle was debilitated when captured 3 days after spraying. It was held overnight, then released, but was recaptured later at the release site and sacrificed to obtain ChE measurements. We located 9 of the remaining 10 tawny eagles at least once after spraying in an area with dead and dying quelea. Three tawny eagles fed in or near both colonies after spraying, and 2 fed in a third, unsprayed colony in the area as young became available. Only 1 of 3 bateleur eagles was located in areas with affected quelea. All 4 pale

Table 1. Fenthion residues (μg) on young, flightless quelea debilitated by spraying with fenthion in Kenya, 1985.[a]

Days after spraying	Colony: Crocodile $\bar{x}$	Crocodile SE	Ranch $\bar{x}$	Ranch SE
1	44.0	7.4	83.7	9.5
2	6.5	1.2	19.7	2.8
3	8.6	1.3	10.9	1.2
4			12.2	2.3

[a] Birds collected alive under nest trees; n = 6 for all collections except Crocodile Colony, Day 1, where n = 15.

chanting goshawks, both gabar goshawks, and both pygmy falcons foraged in and near areas with dead or dying quelea.

Food Contamination

Dead and dying insects were present throughout both colonies on the morning after each spray. Residue levels on dead insects collected in Ranch Colony 18–24 hours after spraying ranged from 0 to 23.0 μg, but fenthion was found on 25 of 27 samples. The highest residue level (23.0 μg) was found on a sample of carabid beetles, but residues of 0.89–11.0 μg found on samples of Orthopterans in both colonies were consistently higher than residues on most other samples. The total weight of all insects in the 15 samples from Ranch Colony was 8.5 g, and, in the aggregate, those samples contained 61.3 μg of fenthion.

Fenthion residues on grasses were 38 and 28 ppm in Crocodile and Ranch colonies, respectively, on the first day of sampling, but had decreased to 1.9 ppm on the third day and 1.1 ppm on the fourth day after spraying in the 2 colonies, respectively. The sample of millet in the center area of Crocodile Colony was contaminated with residues of 1.1 ppm fenthion.

Cholinesterase Levels

ChE activity in brains of quelea averaged 47 μmol/g (SE = 4.25, range = 35–61) for adults and 42 μmol/g (SE = 1.7, range = 38–56) for young before spraying. ChE levels in flightless, debilitated young (n = 30) picked up alive under nest trees in Crocodile Colony during the first 4 days after spraying averaged 12 μmol/g (SE = 0.91, range = 5–28), less than levels in prespray young (F = 270; 1,38 df; P = 0.0001). ChE levels in apparently normal young quelea, mist-netted while flying in Crocodile Colony 4 days after spraying, averaged 21 μmol/g (SE = 5.3, range = 12–36) and were not different (F = 3.1; 1,8 df; P > 0.10) from average ChE levels of 10.4 μmol/g (SE = 3.1, range = 4–25) of debilitated young collected 4 days after spraying, suggesting that normal-appearing birds may also have been exposed to fenthion.

Adult quelea in cages exposed to fenthion applications showed variations in effects that appeared related to location of cages. Most birds exposed in cages on the ground in Crocodile Colony died within 24 hours. Single birds sampled from the colony center and 100 and 200 m downwind had reduced ChE activity (10.9, 12.9, and 16.1 μmol/g, respectively). Three of 4 birds in a cage 300 m downwind from the center of Ranch Colony showed ChE depression (12.9–14.5 μmol/g), and those 3 died. Two quelea caged in a tree at the colony center did not show much ChE depression (26.9 and 37.2 μmol/g), but both died within 20 hours of exposure.

Three tawny eagles, captured before the first fenthion applications, were the only raptors known to be free from exposure to fenthion. These eagles had ChE activity levels in blood of 1,416, 1,418, and 1,437 mU/ml. Because eagles move considerable distances, any of those in the general area could have received exposure after fenthion was first applied. Of 7 tawny eagles from which blood samples were taken after spraying, 5 had blood ChE activity <900 mU/ml and, therefore, probably were exposed to fenthion. Only 2 of the 5 appeared physically affected. Brain ChE activity in 2 other debilitated eagles was <10 μmol/g, and their ultimate survival was questionable. One normal-appearing eagle collected after spraying in Ranch Colony had 5 quelea in its gut and had the lowest ChE activity in both blood (136 mU/ml) and brain (7.6 μmol/g) of any eagle examined. Many other eagles in the area (about 30 in the colonies at any time and 75–100 in the area) probably were similarly exposed.

Three apparently unaffected bateleur eagles were captured after the first spray. ChE activity in their blood was among the highest measured in any raptor: 2,320, 2,047, and 1,474 mU/ml. A sick pygmy falcon observed eating dead quelea had ChE activity of 623 mU/ml in blood and 7.1 μmol/g in brain. A male and female pygmy falcon pair had similar ChE activity levels in blood (888 and 661 mU/ml, respectively) and probably had been exposed to fenthion. A fourth pygmy falcon had ChE activity of 1,264 mU/ml in blood, despite its capture near Crocodile Colony after fenthion applications.

A pale chanting goshawk observed eating dead quelea had the lowest ChE activity in blood (513 mU/ml) measured for this species. Two others had ChE levels of 627 and 785 mU/ml, similar to ChE levels of 632 and 663 mU/ml found in 2 gabar goshawks. All 5 goshawks were located regularly in the colony areas and undoubtedly had been exposed to fenthion. A single pearl-spotted owlet found moribund had ChE activity in brain of 6.3 μmol/g, also suggesting exposure to fenthion. ChE activity <900 mU/ml in blood of raptors seemed to indicate fenthion exposure, and this suggested that 16 of 23 raptors examined after spraying were affected by the sprays.

We identified 94 species of birds in or around the colonies during our 11-week study. Forty-four birds of 17 species other than quelea were found dead during 71 hours of searches in or near colonies after fenthion application. With such high scavenging rates, it is likely that the 44 debilitated or dead nontarget birds found during postspray searches represented only a small percentage of the number of nontarget birds actually affected.

Levels of ChE activity in brains of birds varied among species. ChE levels in some species were not influenced by their exposure to fenthion, while levels were lower in exposed birds of other species (Table 2). In most species, debilitated individuals had low ChE activity in brain. For the species tested, ChE activity of ≤20 μmol/g suggested exposure to fenthion, while most debilitated and moribund birds had levels ≤10 μmol/g.

DISCUSSION

Quelea Mortality

Variation observed in the timing of mortality of both caged and free flying quelea may have been related to differential exposure caused by factors such as droplet size, vegetation canopy, and behavior or relative excitability of birds during applications. Birds with high residues died quickly, and birds alive after 2–3 days that had initially received less exposure survived longer. For adult quelea, it appeared that ChE activity levels in the brain below about 20 μmol/g were indicative of fenthion exposure, and those below about 15 μmol/g were associated with death. Nonetheless, this mortality pattern showed that fenthion can kill slowly, and that birds that appear healthy after exposure may succumb later to either its direct or indirect effects. Such prolonged mortality increases both the total area and time over which raptors and scavengers can be exposed to contaminated quelea. Thomsett (1984) observed quelea dying for ≤19 days following a roost control operation in 1984 in Kenya when a ground sprayer and low-volume techniques were used.

Young quelea collected on the ground below nest trees also had greatly reduced ChE activity in their brains, but many survived for >4 days after spraying. Most quelea collected after spraying showed similar ChE activity in brain, but fenthion residues on their feathers decreased each day after spraying. Although all young in colonies apparently died, it is not clear why it took so long. ChE activity in brain averaged about 10 μmol/g, which is 80% less than the 42 μmol/g measured in 10 unexposed young. Most studies suggest ChE inhibition of about 70% can be expected in birds that die of organophosphate poisoning (Hill and Fleming 1982). Recovery of normal ChE levels in

Table 2. Mean levels of cholinesterase activity (μmol/min/g) in brains of unexposed and exposed nontarget bird species following fenthion sprays in 2 quelea colonies in Kenya, 1985.

Species	Unexposed $\bar{x}$	Unexposed SE	Unexposed n	Exposed[a] $\bar{x}$	Exposed[a] SE	Exposed[a] n	Apparent difference (%)
Red-billed hornbill (*Tockus erythrorhynchus*)	27.8		1	34.0		1	+22.3
Donaldson-Smith's nightjar (*Caprimulgus donaldsoni*)	23.8		1	27.8		1	+16.8
Harlequin quail (*Coturnix delegorguei*)	21.0	0.7	6	22.6	1.5	4 (1)	+7.6
Yellow-vented bulbul (*Pycnonotus barbatus*)	31.7	1.1	3	32.6		1	+2.8
D'Arnaud's barbet (*Trachyphonus darnaudii*)	38.6		1	39.5		1	+2.3
Grey-headed sparrow (*Passer griseus*)	32.8	2.9	2	30.3		1	−6.8
Yellow-spotted petronia (*Petronia xanthosterna*)	34.4		1	32.0		1	−7.0
Laughing dove (*Streptopelia senegalensis*)	33.7	1.4	4	29.7	1.3	10	−11.9
Pink-breasted lark (*Mirafra poecilosterna*)	24.5	0.9	2	20.8		1	−15.1
Fischer's starling (*Spreo fischeri*)	30.8	2.1	2	21.6		1	−29.9
Golden-breasted starling (*Cosmopsarus regius*)	28.6	1.4	2	17.0	0.2	2	−33.6
White-headed buffalo weaver (*Dinemellia dinemelli*)	28.1	0.9	5	17.2	6.2	2 (1)	−38.8
Superb starling (*Spreo superbus*)	31.6		1	18.7		1	−40.8
Golden-breasted bunting (*Emberiza flaviventris*)	33.4	1.2	2	19.1		1 (1)	−42.8
Red-billed buffalo weaver (*Bulbalornis niger*)	27.1	1.6	3	14.6	2.3	2	−46.1
White-crowned shrike (*Eurocephalus ruppelli*)	26.4	3.7	3	10.5	2.5	3	−60.2
Blue-naped mousebird (*Colius macrourus*)	31.8	2.2	2	7.8	0.6	8 (7)	−75.5
Red bishop (*Euplectes orix*)	36.4	1.7	11	8.6	1.0	4 (4)	−76.4
Masked weaver (*Ploceus intermedius*)	33.0		1				
Ring-necked dove (*Streptopelia capicola*)	40.9		1				
Cut-throat (*Amadina fasciata*)				4.8		1 (1)	

[a] Number debilitated in parentheses.

affected birds can occur, although it may require ≤30 days (Grue et al. 1983).

We were surprised, nonetheless, that young quelea survived so long without apparent food and water, especially with greatly reduced ChE levels. Pope and Ward (1972) stated that in routine spray operations, using existing techniques, quelea died in <12 hours. However, at the time, application rates were greater and fenthion was applied in diesel oil (Anon. 1979). M. M. Jaeger (FAO, pers. commun.) also observed birds dying in <12 hours following sprays with application rates similar to those used in our study, when fenthion was also mixed in diesel oil and sprayed to produce droplets of 100–200 μm.

Impact of Fenthion on Raptors

We found no dead eagles, but 5 of 7 tawny eagles showed reduced ChE activity and 2 appeared debilitated. Of 23 raptors examined after spraying, 16 had depressed ChE levels. Most of the 75–100 raptors observed in and around our study areas could have been exposed to fenthion sprays. Radiotelemetry data indicated that some raptors, especially tawny eagles and pale chanting goshawks, concentrated their foraging activities within treated colonies, and 3 tawny eagles even moved from Crocodile Colony to Ranch Colony after Ranch Colony was sprayed. Other raptors, such as bateleur eagles, roamed more widely outside the colony areas for food.

Although some raptors, particularly owlets roosting in Ranch Colony, may have been sprayed by fenthion, most raptors undoubtedly received their greatest exposure to fenthion from eating affected quelea, which the larger raptors ingest whole. Acute oral toxicity of fenthion to American kestrels (*Falco sparverius*) is 1.3 mg/kg (Schafer 1972). If ingestion of about 1.0 mg/kg fenthion is sufficient to kill some raptors and debilitate others, then young quelea coated with 50.0 μg of fenthion pose a hazard to these birds. Tawny eagles, weighing 2 kg, would receive a 1.0-mg/kg dose upon eating 40 quelea (2.0 μg fenthion), while a pale chanting goshawk (600 g) would need to eat 12 quelea, and a pygmy falcon (60 g) only 1.2 quelea, to receive such a dose. These rates of quelea consumption are realistic and can be expected. In quelea colonies sprayed with parathion in Mali, Thiollay (1975) found dead eagles with 16 young quelea in their stomachs. He also reported that eagles normally will eat 30–40 4- to 8-day-old quelea each day (J.-M. Thiollay, Cent. Natl. de Recherches Sci., France, pers. commun.). It would require only 50% as many quelea to provide lethal doses if each carried 100 μg of fenthion, which many young quelea did contain the day after spraying; others may have been considerably more contaminated.

In our study, eagles and other raptors would have received severe exposure only the first day following application of fenthion. Residues on live, affected quelea decreased rapidly, and raptors would have had to eat greater numbers of young to receive serious exposure even 1 or 2 days later. However, when several colonies are sprayed in the same areas, raptors that feed on them successively become increasingly susceptible to poisoning.

Doves, quail, sandgrouse, and domestic chickens exposed in cages showed no signs of debilitation or intoxication, and none died following exposure. Likewise, quail that we collected in colonies, and that we assumed had been exposed, showed neither debility nor ChE depression. Jackson and Park (1973) also noted that they did not find any dead helmeted guinea fowl (*Numida meleagris*), another gallinaceous species, following fenthion sprays in Chad. These results were not expected because North American species of doves, pigeons, and quail are highly sensitive to oral doses of fenthion which they might obtain from eating contaminated seeds (LD_{50}'s of 2.5, 4.6, and 10.6 mg/kg, respectively [Hudson et al. 1984]). M. M. Jaeger (FAO, pers. commun.), however, has found dead or debilitated vulturine guineafowl (*Acryllium vulturinum*) following sprays of quelea roosts in Ethiopia.

Impact of Fenthion on Insects and Insectivorous Birds

Fenthion is not a selective pesticide; extensive mortality was found in 14 families of insects and in spiders. Residues on insects varied among families, with highest levels present on Carabidae, Acridiidae, Gryllidae, Tettigoniidae, and Mantidae. Although insectivorous birds roost or nest in vegetation associated with quelea colonies, insect residues probably were the source of exposure to many of the affected insectivorous birds. If the lethal dose of fenthion to a 25-g insectivorous bird were about 2.5 mg/kg, then it would be killed by eating insects contaminated with 62.5 μg of fenthion. Most insectivorous birds probably would consume ≥33% of their body weight each day. Based on our finding of 61.3 μg of fenthion in the 8.5-g sample of insects in Ranch Colony, insectivorous birds could receive a fenthion dose of about 2.5 mg/kg on the day after spraying.

About 50% of the 21 passerine species collected, other than quelea, had been exposed to fenthion. In the exposed species, about 25% of the individuals suffered either serious ChE depression, debility, or death. However, fenthion has many other influences on the physiology of animals (Eastin et al. 1982, Grue et al. 1983), and the impact of long-term sublethal effects of cumulative exposure is unknown.

Fenthion residues found on grasses could be a hazardous source of exposure to insects and possibly herbivores if consumed over a number of days. Based on 1.1-ppm residues found on the exposed millet, contaminated grass seed in colonies could present some hazard to seed-eating birds if these residues persisted. For instance, the LC_{50} of fenthion to bobwhite quail (*Colinus virginianus*) over 5 days is 30 ppm (Heath et al. 1972). However, fenthion is highly susceptible to oxidation and, in the presence of sunlight and air, is known to be transformed rapidly into its sulfoxide and sulfone metabolites, which in turn are quickly decomposed (Metcalf et al. 1963).

CONCLUSIONS

Nontarget birds should be considered when conducting spray operations for quelea control. During 1985 in the eastern Africa countries of Tanzania, Sudan, Somalia, Kenya, and Ethiopia, 277 quelea concentrations, totaling 23,370 ha were sprayed with a total of 39,417 L of Queletox (Nurien and Ndege 1986). The potential impact on the environment and nontarget wildlife from this magnitude of spraying is enormous.

On our study sites, fenthion applications caused massive mortality to quelea and insects, and exposed predatory and insectivorous birds to potentially harmful residues. Most granivorous species of birds (other than quelea) apparently were not affected. Environmental and food chain contamination was short-lived, but this aspect requires further study. Our radiotelemetry data showed that raptors were highly mobile and preyed sequentially upon several colonies as young quelea became available. Consequently, raptors are susceptible to cumulative effects of fenthion contamination, increasing ChE depression, and ultimately death.

Numerous species of insectivorous and granivorous birds were present in or near quelea colonies during control operations; we tallied 94 species during our 4-week study. Morel and Morel (1978) recorded 112 species (not including Accipitridae and Falconidae) in an area of only 25 ha in northern Senegal over an 8-year period. Affected nontarget birds often are not found after control operations because of a lack of systematic and intensive searches for them and their removal by scavengers.

It has been assumed that lower spray rates would reduce hazards to nontarget species. This assumption may not be valid; in fact, low-volume application techniques may actually increase environmental contamination (Keith 1968). For this reason, proposals to reduce spray quantities and further develop low-volume ground sprayers, which emit even smaller droplets, should be evaluated thoroughly before being recommended for general use. Chemicals, application rates, and techniques that kill quelea more rapidly in the nesting colony when raptors are absent, thereby reducing opportunities for predatory and scavenging species to feed on them, should be investigated. We also recommend greater selectivity in the choice of sites and timing of spraying. Control should be avoided when young leave the nest, the highly attractive period to raptors.

SUMMARY

Two nesting colonies of quelea in Kenya, 10 and 40 ha in size, were sprayed with 40 and 100 L of Queletox (60% fenthion), respectively. Fenthion applications caused massive mortality to quelea and insects. Predatory and insectivorous birds were exposed to short-lived, but severe and potentially harmful, residues. In both colonies, quelea died during a 4- to 7-day period. In the larger colony, dead and dying birds were found over an area of ≤ 35 km^2. Nontarget, granivorous bird species appeared unaffected. Of 24 radio-equipped raptors tracked for ≤ 17 days after spraying, only 2 were found moribund. However, based on cholinesterase depression, 16 of 23 raptors examined after spraying were thought to have been exposed. Using fenthion as an avicide presents lethal and sublethal threats to predatory and insectivorous birds.

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